Refractive indices with Haag-Streit Lenstar biometer

Marwan Suheimat, Pavan K. Verkicharla and David A. Atchison*
Institute of Health & Biomedical Innovation and School of Optometry & Vision Sciences, Queensland University of Technology, Kelvin Grove Q 4059 Australia
*Corresponding author: d.atchison@qut.edu.au

Purpose: To estimate refractive indices used with the Lenstar biometer. Methods: Axial lengths of model eyes were determined using an IOLMaster biometer and a Lenstar; comparing these lengths gave an overall eye index for the Lenstar. Using the Lenstar Graphical User interface, we determined that boundaries between media could be manipulated so that there were opposite changes in optical pathlength on either side of the boundary and specified changes in distances determined the ratios of media indices. These ratios were combined with the overall eye index to estimate indices. Results: The IOLMaster and Lenstar produced axial length estimates to within ±0.01 mm. Estimations of group refractive indices were 1.340, 1.341, 1.415 and 1.354 for cornea, aqueous, lens and overall eye, respectively. The aqueous and lens indices, but not those for the cornea, are similar to schematic eye indices and reasonable lens indices. Conclusion: The Lenstar appears to use different refractive indices for different ocular media.

Keywords: axial length; refractive index; Lenstar; partial coherence interferometry

1. Introduction

Two commercial instruments use partial coherence interferometry to measure eye lengths: the IOLMaster (Carl Zeiss Meditec AG, Jena, Germany) and the Lenstar LS 900 biometer (Haag Streit, Bern, Switzerland). The IOLMaster determines axial length, but not internal distances with partial coherence interferometry. It uses an average group refractive index of 1.3549 at 780 nm for the eye to convert optical pathlength of the eye into a physical axial length [1-2].

The Lenstar determines corneal thickness, anterior chamber depth, lens thickness, and axial length. The vitreous chamber depth is obtained by subtracting the sum of internal distances from the axial length. A broadband source has a central wavelength of 820 nm. The Lenstar uses an average refractive index for the calculation of axial length [3]. We understand that such an index is chosen to give axial lengths that closely match those given by the IOLMaster. It is not known whether this average index is used for the other media or whether they have their own indices.

The assumptions in the design and programming of commercial instruments are proprietary information that can likely be accepted if used for the intended application. Extending their use, such as to determining off-axis eye lengths or possible changes in axial length due to accommodation, requires understanding the principles and assumptions in order to estimate errors and to introduce correction factors as necessary. We are using the Lenstar to estimate retinal shape, and here describe an investigation into determining refractive indices that it assumes.

2. Methods

The axial lengths of several model eyes were determined using both an IOLMaster and a Lenstar. We estimated a group refractive index n_{avg} for the Lenstar by comparing these lengths and taking into account difference in wavelengths for the instruments.

Using the A-scan screen in the Lenstar Graphic User Interface (GUI), each ocular boundary of a real eye was shifted in small steps (Figure 1). This caused different changes in the geometrical lengths on either side of the boundary. The change in one medium's thickness was plotted against the change in the other medium's thickness to give a linear curve with a negative slope (Figure 2). Assuming that the optical pathlengths changed equally as the boundary was moved, this slope *m* is the ratio of the two media refractive indices:

$$m = \Delta x_2/\Delta x_1 = -n_1/n_2 \tag{1}$$

where Δx_i is change in physical thickness of medium i with group refractive index n_i.

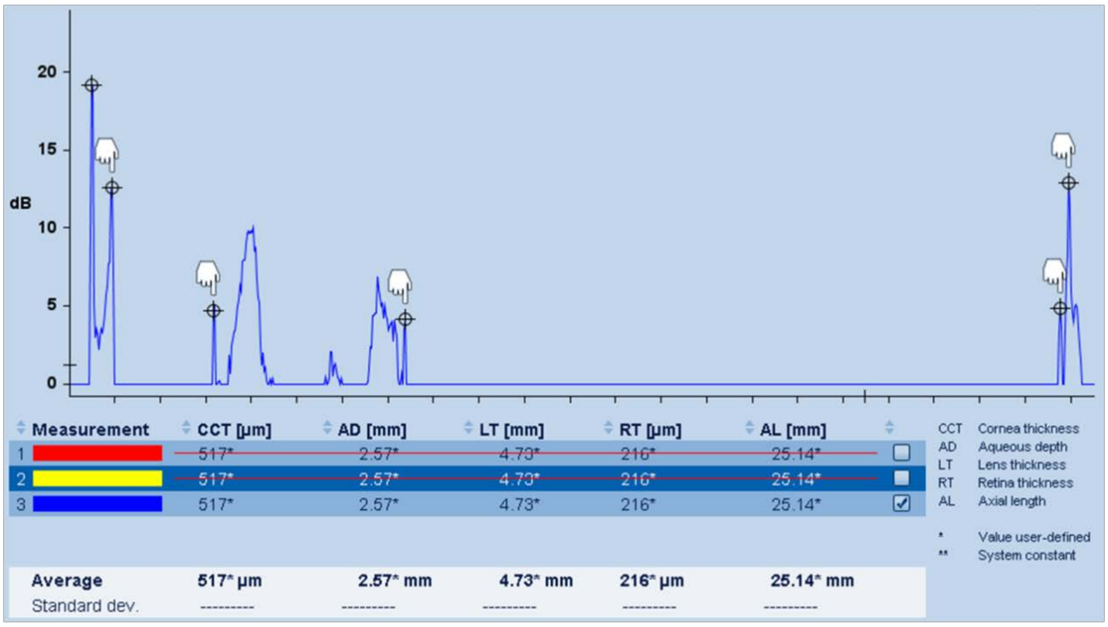

Figure 1. A sample A-scan screen from the Lenstar graphical user interface with points towards all the peaks that can be redefined by the user. The six peaks represent (left-to-right) the reflections from anterior cornea, posterior cornea, anterior lens, posterior lens, internal limiting membrane and retinal pigment epithelium.

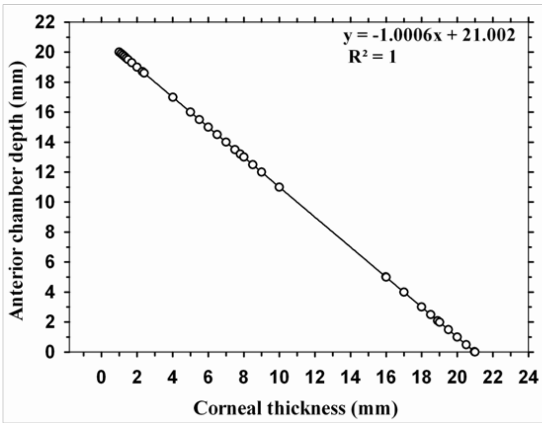

Figure 2. Anterior chamber depth (geometrical) as a function of corneal thickness (geometrical) while sliding the anterior lens boundary; thus equally varying their optical pathlengths. The slope represents the ratio of the assumed group refractive indices of the two media.

The ratio between the average group refractive index of the eye and that of the lens was taken by moving peaks to expand the lens to cover the whole length of the eye, and comparing the thickness of the lens to the axial length reading given by the GUI. The ratio between the indices for lens and aqueous was acquired by sliding the anterior surface of the lens. Similarly, the ratio between the indices for the aqueous and the cornea was achieved by sliding the posterior surface of the cornea.

The indices were compared with indices found in schematic eyes. The refractive indices in these eyes were corrected from 555 nm to 820 nm using two approaches. In the ‘water scaling’ approach, we assumed chromatic dispersion similar to water at 20°C[4]. The refractive index at 820 nm was

$$n_{820} = n_{555} \times n_{820,water} / n_{555,water} \qquad (2)$$

As the indices in this equation are phase indices applicable to single rays, n_{820} was converted to a group index applicable to wave bundles using

$$n_g(\lambda) = n_p(\lambda) - \lambda \frac{dn_p}{d\lambda} \qquad (3)$$

where $n_g(\lambda)$ and $n_p(\lambda)$ are group and phase indices at wavelength λ. In the ‘Atchison & Smith’ approac , we used Cauchy dispersion formulae of ocular media [5]. These formulae apply for the phase indices of the Gullstrand No. 1 eye, and, as necessary, scaling was used:

$$n_{820} = n_{555} \times n_{820,Gull} / n_{555,Gull} \qquad (4)$$

Conversions from phase indices to group indices were made using equation (3).

3. Results

Using several physical model eyes, axial lengths were measured using the IOLMaster and Lenstar. The instruments produced the same estimates of axial length to within ±0.01 mm. It follows that the average refractive index assumed by the Lenstar can be estimated by different optical pathlengths due to the different instrument light sources. Multiplying the average group refractive index used in the IOL Master[1] by the ratio of group indices of water at 820 nm and 780 nm , n_{avg} for the Lenstar was estimated as:

$$\boldsymbol{n_{avg} = n_{IOL} \times n_{820,waterg} / n_{780,waterg} = 1.3549 \times 1.3421/1.3429 = 1.3540}$$

Table 1 shows both the ratios between the group refractive indices of ocular media, obtained from the Lenstar GUI, and the estimated group refractive indices using 1.3540 for n_{avg}.

Table 1. Estimated effective refractive indices of ocular media used by the Lenstar GUI.

Ocular medium	Ratio	Estimated effective refractive index
Lens	n_L/n_{avg} = 1.0450	1.4149
Aqueous	n_{AQ}/n_L = 0.9475	1.3406
Cornea	n_C/n_{AQ} = 0.9994	1.3398

Table 2 shows group refractive indices of the Gullstrand No. 1 eye and the Le Grand full theoretical eye according to the approaches in the Methods. The Gullstrand eye lens indices are based on its average phase index 1.3994 at 555 nm. For the Le Grand eye, the lens gradient index has been replaced by an “equivalent index” in order to give the correct power.

Using Table 1 and Table 2 values, Table 3 shows ratios of estimated group refractive indices of the Lenstar and those of the schematic eyes. For the cornea, the estimated indices differ considerably by 3.2% from schematic eye indices. For the aqueous the estimated indices differ by only 0.1-0.3% from the schematic eye indices: no distance correction is needed. For the lens, estimated refractive indices vary by –0.9% to +0.6% from schematic eye indices. An accurate value for group refractive index in visible light is about 1.410 for lenses of young adult eyes[5], corresponding to 1.417 group index at 820 nm. This suggests the Lenstar underestimates lens group refractive index by 0.15%, corresponding to distance overestimation of less than 0.01 mm in 4 mm lenses. As 0.01 mm is the resolution limit for the lens, no distance correction is needed.

Table 2. Group refractive indices of Gullstrand No. 1 and Le Grand schematic eyes - 820 nm.

Eye model/approach	Cornea	Aqueous	Lens	Vitreous
Gullstrand/water scaling	1.3834	1.3435	1.4066	1.3434
Le Grand/water scaling	1.3844	1.3449	1.4271	1.3434
Gullstrand/Atchison&Smith	1.3823	1.3423	1.4063	1.3419
Le Grand/Atchison&Smith	1.3834	1.3437	1.4270	1.3419

Table 3. Ratio of estimated group refractive indices of Lenstar and those of schematic eyes - 820 nm.

Eye model/approach	Cornea	Aqueous	Lens
Gullstrand/water scaling	0.9685	0.9978	1.0059
Le Grand/water scaling	0.9678	0.9968	0.9915
Gullstrand/Atchison&Smith	0.9693	0.9987	1.0061
Le Grand/Atchison&Smith	0.9685	0.9977	0.9915

4. Conclusion

We estimated group refractive indices used to determine lengths within the eye as 1.340, 1.341, 1.415 and 1.354 for cornea, aqueous, lens and overall eye, respectively. The aqueous and lens indices, but not the index for the cornea, are similar to schematic eye indices and reasonable lens indices.

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